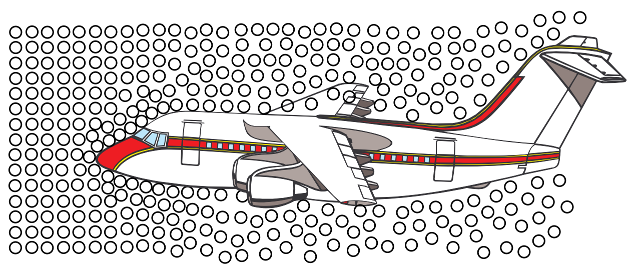
Student Reading

Air is not empty

To fly, you must pass through the air. Even though we cannot see the air, it is not empty. The air is made up of millions of little molecules that push against our bodies. These particles of air take up space or "have volume". They are made up of matter so they have "mass", too. They also have "weight". Air can exert a tremendous amount of pressure and force. As you rise higher in elevation, like taking a drive into the mountains, you can feel that your ears need to "pop". The air pressure on the outside of your eardrum becomes lower as you gain altitude. You are feeling the greater **air pressure** inside your inner ear pressing against your eardrum.

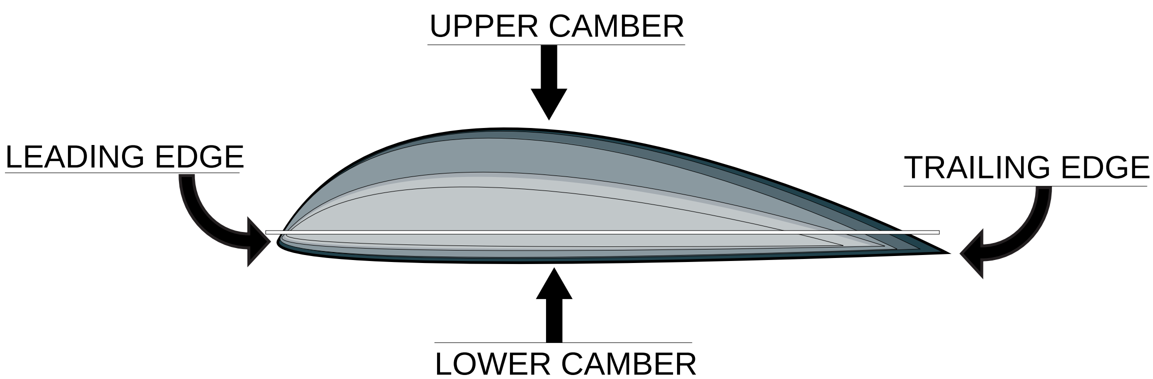
You can feel the air pushing against you when the wind blows, too. When you move through a room, you push against the air. You change where the air is located and what the air is doing. Knowing that air is not empty space, but is made up of molecules, led to some important understandings of how the wings on an airplane help it to fly.



Air molecules being pushed aside by the airplane.

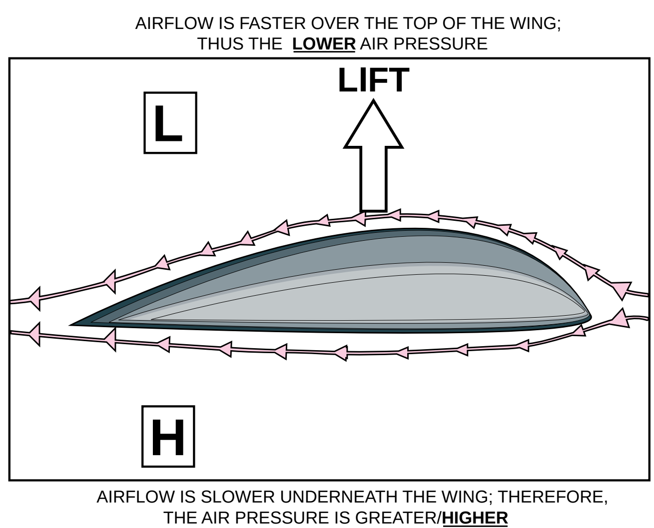
Wings and Flight

Have you noticed the curved shape of a bird's wing? An airplane's wing is curved also. A wing is designed for flight. It has a special shape called an **airfoil.** An airfoil shape is used on wings, fans and propellers. The airfoil shape gives a lifting (**aerodynamic**) force when the air flows around it.

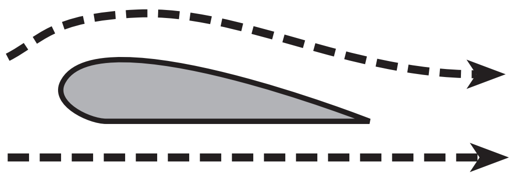


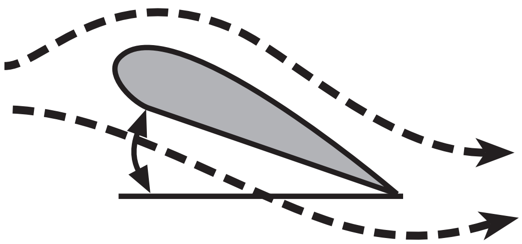
An airfoil has a thicker leading edge (front end) and a very thin trailing edge (back end). In between the leading edge and the trailing edge, an airfoil is curved on both the top and the bottom surfaces. Usually though the top surface has more of a curve than the bottom surface. When a surface is curved like that, we say that it has **camber.**

An airfoil uses Bernoulli's Principle. Since the top surface of the wing has more camber (curve) than the bottom surface, the air flows faster over the top of the wing than it does underneath. The faster **airflow** over the top of the airfoil has lower pressure than the airflow underneath. With greater air pressure underneath and lower air pressure on top, the airfoil will lift. Bernoulli's Principle was discovered by the scientist Daniel Bernoulli. He discovered that fast flowing fluids (in this case, water), had lower pressure than slower flowing fluids. This also held true for airflow.



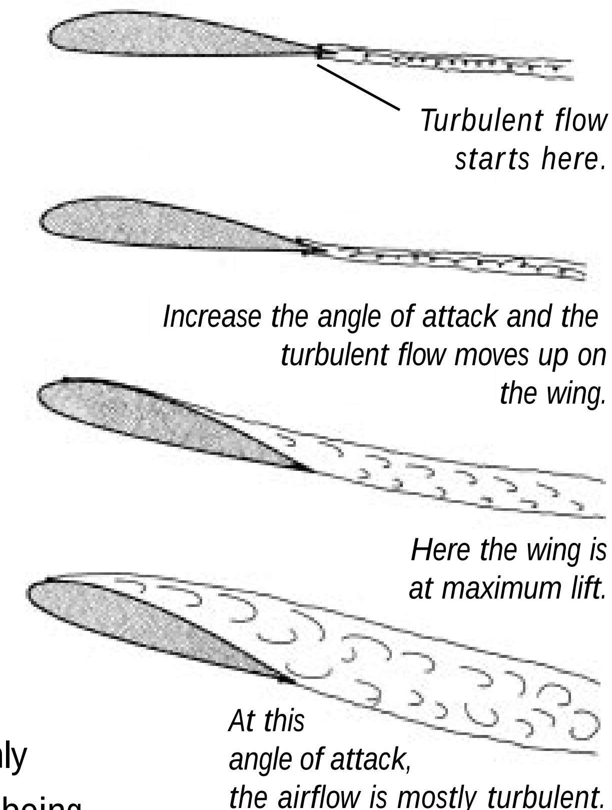
Angle of Attack


0˚ angle of attack


20˚ angle of attack

Because of an airfoil's shape, it will generate (make) lift as it moves through the air. To generate even more lift, we can change the wing's angle of attack. **Angle of attack** is the angle at which the leading edge of the wing meets the oncoming air. By tilting the leading edge up (or increasing the angle of attack), it will change the speed of the airflow. The air flowing over the top of the now upward-tilted wing will flow at an even greater speed than the air moving under the wing. This increases the difference between the air pressure underneath the wing and the air pressure over the wing. This increased difference generates even more lift. As an airplane speeds along the runway during takeoff, the airfoil-shaped wings are generating some lift. Farther along the runway, the pilot pulls the nose of the airplane up. This increases each wing's angle of attack and causes even more lift to be generated. The airplane rises even more as it lifts off the ground and heads skyward.

Angle of Attack (Continued)



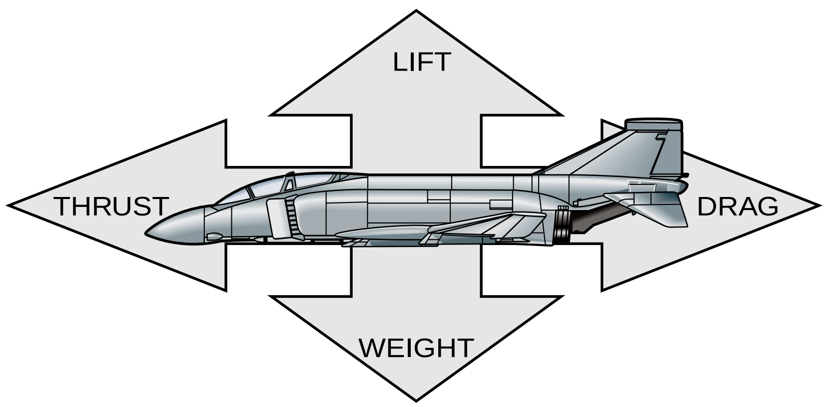
However, there can be too much of a good thing! The airfoil's ability to create lift depends upon the airflow around the wings being smooth. Think of a stream flowing gently around a smoothly rounded rock. The stream changes direction to go around and over the rock, but the flow remains smooth. If the rock were not smoothly rounded, but jagged with a rough surface, the flow would be different. The flow would be rough and choppy. The water might even appear to become jumbled up as it flows by. The same thing happens with the airflow around a wing. If the angle of attack becomes too great, the air stops flowing smoothly around the wing. If this happens, lift stops being generated. We call smooth airflow **laminar** flow. Choppy and jumbled airflow is called **turbulent** flow. When the airflow becomes too turbulent the airplane will **stall**. That means it stops generating lift. When that happens its weight force becomes too strong to keep the airplane up.

So we see how the airfoil shape can generate lift, but if the wing is tilted at an even greater angle of attack, then even more lift will be generated. As long as the airflow around the wing remains smooth (laminar airflow), lift will continue to be generated. If the air flowing around the wings becomes jumbled (turbulent airflow) then the wings will stop making lift.

Forces in Aeronautics

A **force** is a push or pull. This push or pull can move in any direction. A force can also be measured. In aeronautics, four important forces are at work. These forces are called weight, lift, thrust and drag. All of the four forces work in a specific direction. Their magnitude (or how strong the force is) can be measured. Their magnitude can range from very weak to very strong.

Weight is a force that you are probably already familiar with. When you step on a scale, you are checking your weight. What you are actually doing is measuring the pull of Earth's gravity on your body. An airplane has a weight force, too. Even as an airplane flies thousands of feet above the Earth, its **weight** force is pulling it toward the ground. The **lift** force is generated by the airflow around an airplane's wings. When the lift force is greater than the airplane's weight force, the airplane will be able to fly. A large 747 jetliner needs to generate a great amount of lift in order to fly. The Wright Brothers' 1903 *Flyer* did not need to create as much lift because it weighed only 605 pounds. For the jetliner to get enough lift for takeoff, its wings will need to be pushed through the air at a high rate of speed. This is done with powerful jet engines. The force created by the engines is called the **thrust** force. Working opposite the thrust force (and slowing its speed) is drag. As an airplane flies, it pushes aside all those molecules in the air. Some of the molecules flow over the top of the airplane and its wings, while others flow underneath. The air molecules resist this separation. They rub against the airplane as it passes through them. This resistance is called **drag**. The thrust force must be stronger than the drag force in order for an airplane to be able to move forward.



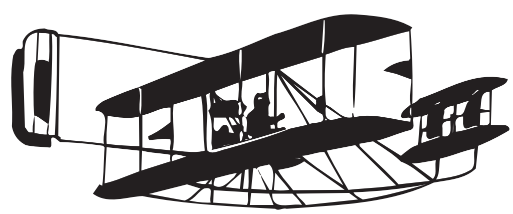
These aeronautical forces work in opposition to each other. That means, lift pulls opposite to weight and drag pulls opposite to thrust. All four of these forces are hard at work when an airplane is flying. Although they work in opposite directions from each other, they all work together to make an airplane fly.

The 1903 Wright *Flyer* and Aeronautics

Before the Wright Brothers started constructing their airplane, they began by doing research. They wrote to the Smithsonian and asked to be sent all the research that had previously been done on the study of flight. They thoroughly read all the research and decided that there were three main problems that needed to be solved:

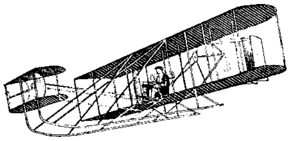
1. They needed to design wings that could generate enough lift to raise a heavy airplane (with a person and an engine) into the air.
2. They needed to make an engine that would be lightweight, yet able to power the airplane through the air.
3. They needed to develop a system to control the airplane while in flight.

At first they used the research they had collected to guide them. Soon, though, they realized that some of the information was incorrect. They found they had to perform their own research. They did tests on airfoil shapes to determine which shape gave the greatest amount of lift. To do this research, they created their own wind tunnel and measuring system. They used this information to change the camber of the wings used on the 1903 Wright *Flyer* to improve its lift. Much of this original research is still true today.



The Wright Brothers understood that they could not take any motor, place it on their airplane and expect the airplane to fly. They knew they needed not only a small, lightweight engine, but also a powerful engine. Small, lightweight powerful engines had not been invented at that time. They also needed to have that engine generate enough thrust to turn large propellers. With the help of their mechanic, they designed their own engine for their biplane.

They also found that no research had been done on aerial propellers. For several months they focused all their energy to study this problem. They were the first to understand how a propeller works. They found that a propeller works just like a wing that is rotating. Once they understood that idea, they were able to design the blades of a propeller for flight.



For control, they created their unique system called wing warping. They developed a hip cradle connected to a series of wires that pulled down on the rear outer edges of the wings.The pilot would control the twisting of the wings by moving his hips to the left or the right. This would maintain the balance and control of the airplane. They also developed a rudder (that worked just like the rudder of a ship) and elevators (that worked like a sideways rudder).

The Wright Brothers remained focused on these problems despite the fact that each problem revealed even more problems to be solved. Their mechanical ability, their research skills and their problem solving skills helped them to persevere to success. They did not stop with the 1903 *Flyer*. They continued to improve their airplane design, and propel the world into the age of flight.

Student Worksheets and Teacher Keys

1. Student Reading
2. Student Comprehension Worksheet
3. Student Comprehension Worksheet Key
4. Vocabulary List
5. Vocabulary Crossword Puzzle
6. Vocabulary Crossword Puzzle Key
7. Team Members and Their Roles
8. Experiment Procedure Card and Data Sheet
9. Experiment Procedure Card and Data Sheet Key
10. Know All the Angles
11. Know All the Angles Key

Wright Flyer Online
Student Reading Comprehension Questions

Directions: Use the student reading to help you answer the questions below.

1. List below 3 characteristics of air.

   1.

   2.

   3.

2. Draw an airfoil shape and label the following:
   1. leading edge
   2. trailing edge
   3. camber

3. In the box below, draw an airfoil shape then show airflow over the airfoil that is, at first, laminar and then turns into turbulent airflow toward the trailing edge.

Wright Flyer Online
Student Reading Comprehension Questions

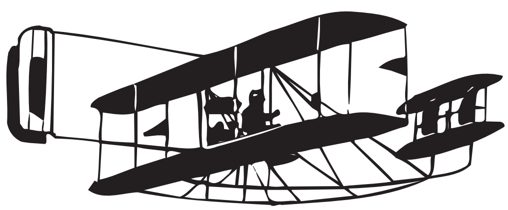
4. List below 3 characteristics of a force.

    1.

    2.

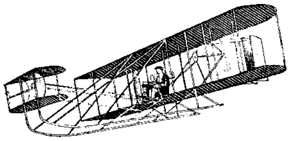
    3.

5. Use the Wright's 1908 *Signal Corp Flyer* below to show how the four forces affect the airplane. (Hint: The front of the airplane is facing right. Use arrows, and label each with the name of the force.)



6. Why did the Wright Brothers make their own wind tunnel?

7. What did the Wright Brothers design in order to solve the problem of airplane control? Explain briefly how it worked.



Wright Flyer Online
Student Reading Comprehension Questions
Key

Directions: Use the student reading to help you answer the questions below.

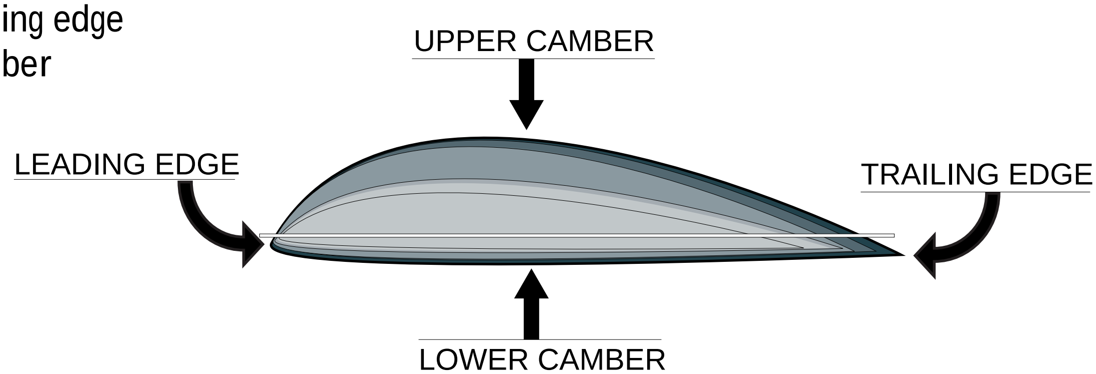
1. List below 3 characteristics of air.

    Acceptable answers:

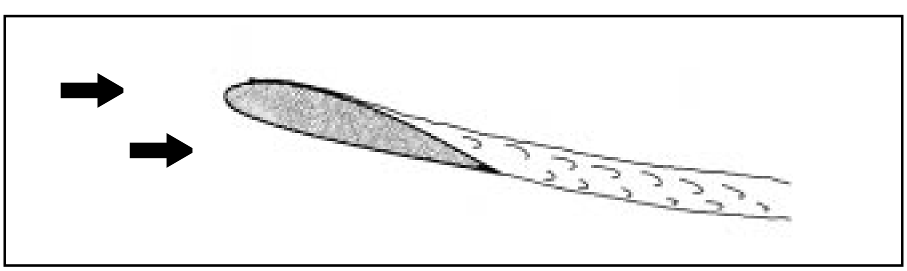
    1. *Air is made up of molecules.*
    2. *These molecules of air have volume (take up space).*
    3. *These molecules of air have mass (made up of matter).*
    4. *These molecules have weight.*
    5. *Air can exert pressure.*
    6. *Air can exert force.*

2. Draw an airfoil shape and label the following:

    1. leading edge
    2. trailing edge
    3. camber



3. In the box below, draw an airfoil shape then show airflow over the airfoil that is, at first, laminar and then, turns into turbulent airflow towards the trailing edge.



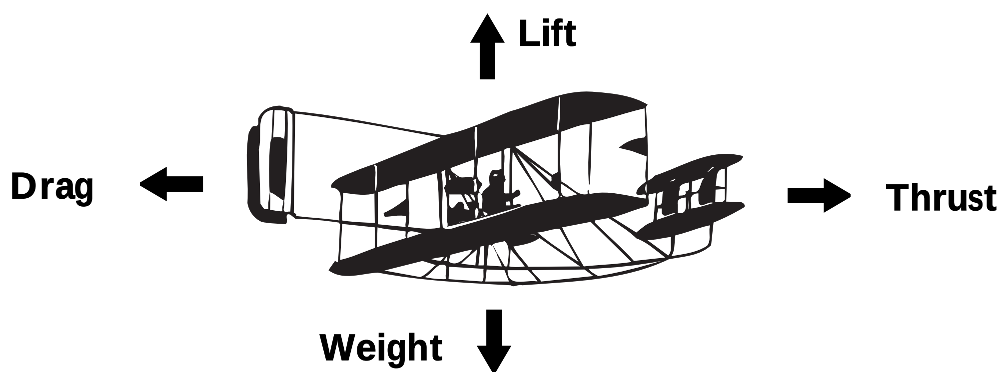
Wright Flyer Online
Student Reading Comprehension Questions
Key (continued)

4. List below 3 characteristics of a force.

   Acceptable answers:

   1. *A force is a push.*
   2. *A force is a pull.*
   3. *A force can be measured.*
   4. *A force can move in any direction.*
   5. *A force has magnitude (strength).*

5. Use the Wright's 1908 *Signal Corp Flyer* below to show how the four forces affect the airplane. (Hint:The front of the airplane is facing right. Use arrows, and label each with the name of the force.)

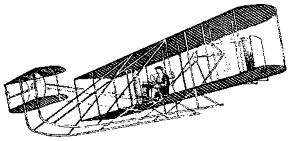


6. Why did the Wright Brothers make their own wind tunnel?

   The Wright Brothers found that earlier research done on airfoil shapes to calculate the amount of lift was incorrect, so they had to build their own wind tunnel and do the tests again. This helped them to design a wing that generated the greatest lift.

7. What did the Wright Brothers design in order to solve the problem of airplane control? Explain briefly how it worked.

   The Wright Brothers created a control system called "wing warping". They attached wires to the trailing edge of the wings and to the hip cradle. The pilot controlled the twisting of the wings' outer edges by sliding his hips left or right.



Aeronautical Vocabulary List

aerodynamic Having a shape that allows for smooth airflow and lift.

air A mixture of gases that surrounds the earth; this mixture is made up of molecules that take up space and have weight.

airflow The motion of air molecules as they flow around an object, such as a wing.

airfoil An object with a special shape that is designed to produce lift efficiently when it is moved through the air.

air pressure The force created by air pushing on a surface.

angle of attack The angle of a wing to the oncoming airflow.

camber The curve of an airfoil.

drag The force that resists the motion of the aircraft through the air.

force A push or pull in a certain direction, that can be measured.

laminar flow The smooth flow of air around an object.

launch angle The angle at which an airplane (most efficiently) takes off.

leading edge The front edge of an airfoil.

lift Upward force produced by air passing over and under the wing of an airplane.

stall A breakdown of the airflow over a wing, which suddenly reduces lift.

Aeronautical Vocabulary List (continued)

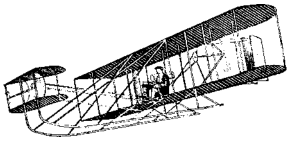
stall angle The angle where the wing meets the oncoming airflow and the wing stops generating lift.

thrust A force created by the engines that pushes an aircraft through the air.

trailing edge The back edge of an airfoil.

turbulent flow Airflow around an object that does not flow in a smooth stream, but swirls about.

weight The force of gravity acting on an object.



Aeronautical Vocabulary Crossword Puzzle

Directions: Use each clue to place the correct aeronautical vocabulary word in its position on the crossword puzzle.

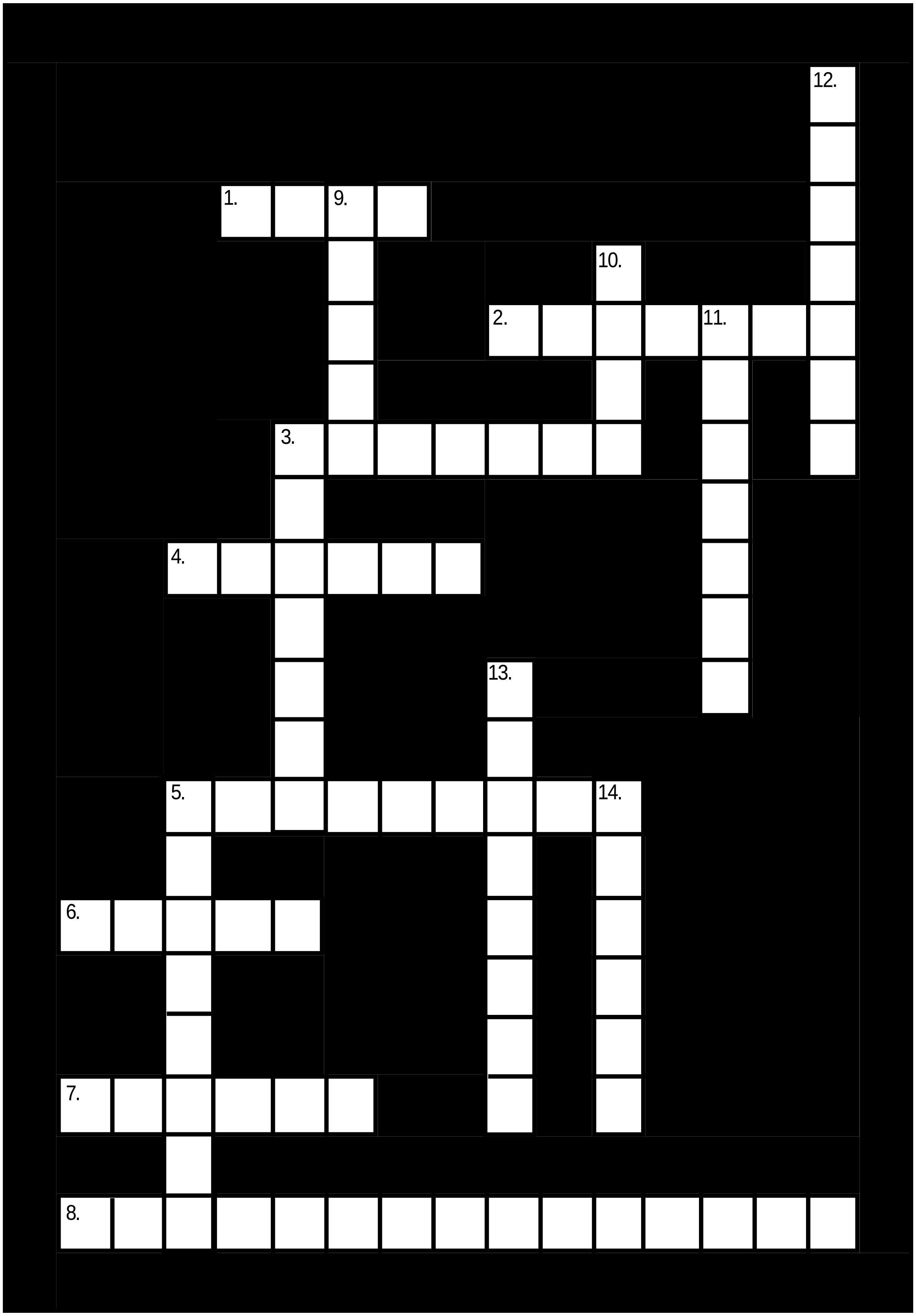
Across

1. This force works opposite of weight.
2. The aerodynamic shape of a wing.
3. The front edge of a wing is the _____edge.
4. The curved part of a wing.
5. The rough or jumbled airflow around a wing.
6. When an airplane stops generating lift.
7. This force works opposite to lift.
8. The angle of a wing as it meets the airflow.

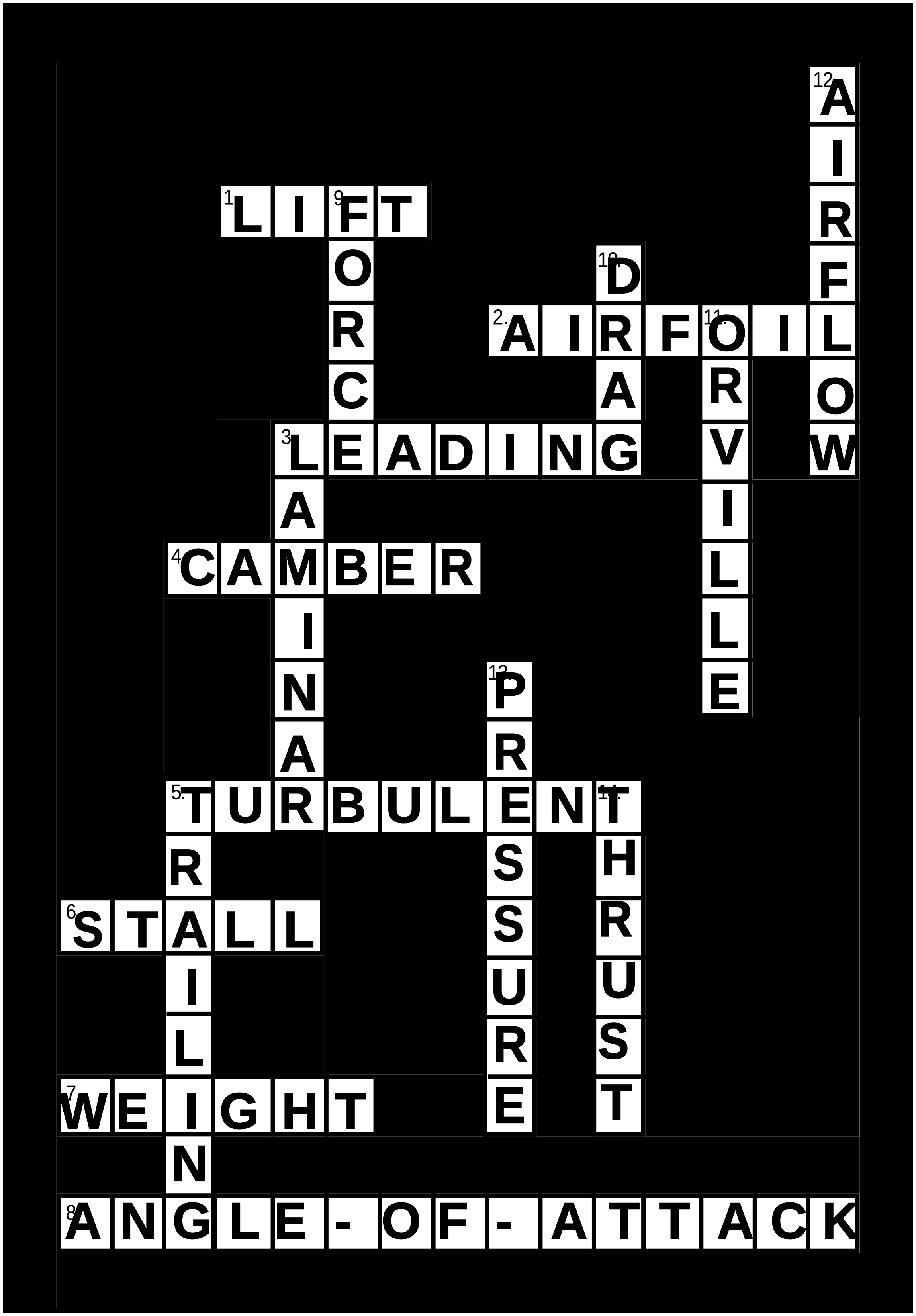
Down

3. The smooth airflow over the wing is this type of flow.
5. The thin, back edge of a wing is the ______ edge.
9. This is a push or a pull.
10. This force is air resistance.
11. One of the Wright Brothers.
12. The movement of air around an airplane.
13. Air pressing down on the Earth.
14. This force moves an airplane through the air.

Aeronautical Vocabulary Crossword Puzzle



Aeronautical Vocabulary Crossword Puzzle - Key



Team Members and Their Roles

Directions: Before you can perform this experiment, each of you must be assigned a certain role or have a certain job to do. For this experiment there are four jobs. Each of the jobs is described below. Before you begin the experiment, make sure that you understand what you will be responsible for during the experiment.

- **Flight Data Recorder**

  This team member records the launch angle and the distance measurements for each flight.

- **Pilot**

  This team member is in charge of launching the airplane. This member must make sure that all airplane parts are securely in place before launch. That means the tail section is firmly in its slot, the wings are centered through the fuselage and are in the back position. The pilot must pull the rubberband back exactly three inches and keep the fuselage of the airplane flat against the launch board.

- **Launch Manager**

  This team member is in charge of measuring the angle of attack on the launch board. The Launch Manager holds the launch board firmly in place at its proper angle. This member also makes sure that the base board does not move as the pilot pulls back on the rubberband. The member also double-checks that the airplane is lying flat against the launch board before takeoff.

- **Spotter**

  This team member follows the airplane's flight and spots the airplane's first point of contact with the ground. Then he or she measures the distance, reports the measurement to the Flight Data Recorder, and then returns the airplane to pilot.

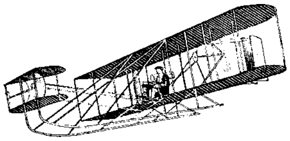
Experiment Procedure Card and Data Sheet

Materials

- Base board (with push pins, rubberbands and protractor attached)
- Launch board
- 3 cardboard anglers
- tape measure
- pencil
- data sheet

Procedure

1. Set launch board at a 10-degree angle.
2. Launch airplane.
3. Observe distance flown and record measurement.
4. Repeat steps 1, 2 and 3 two more times.
5. Set launch board at a 20-degree angle.
6. Launch airplane.
7. Observe distance flown and record measurement.
8. Repeat steps 5, 6 and 7 two more times.
9. Set launch board at a 30-degree angle.
10. Launch airplane.
11. Observe distance flown and record measurement.
12. Repeat steps 9, 10 and 11 two more times.
13. Set launch board at a 40-degree angle.
14. Launch airplane.
15. Observe distance flown and record measurement.
16. Repeat steps 13, 14 and 15 two more times.



Experiment Procedure Card and Data Sheet (continued)

What question do I want to answer?

What do I think will happen during this experiment?

Experiment Procedure Card and Data Sheet (continued)

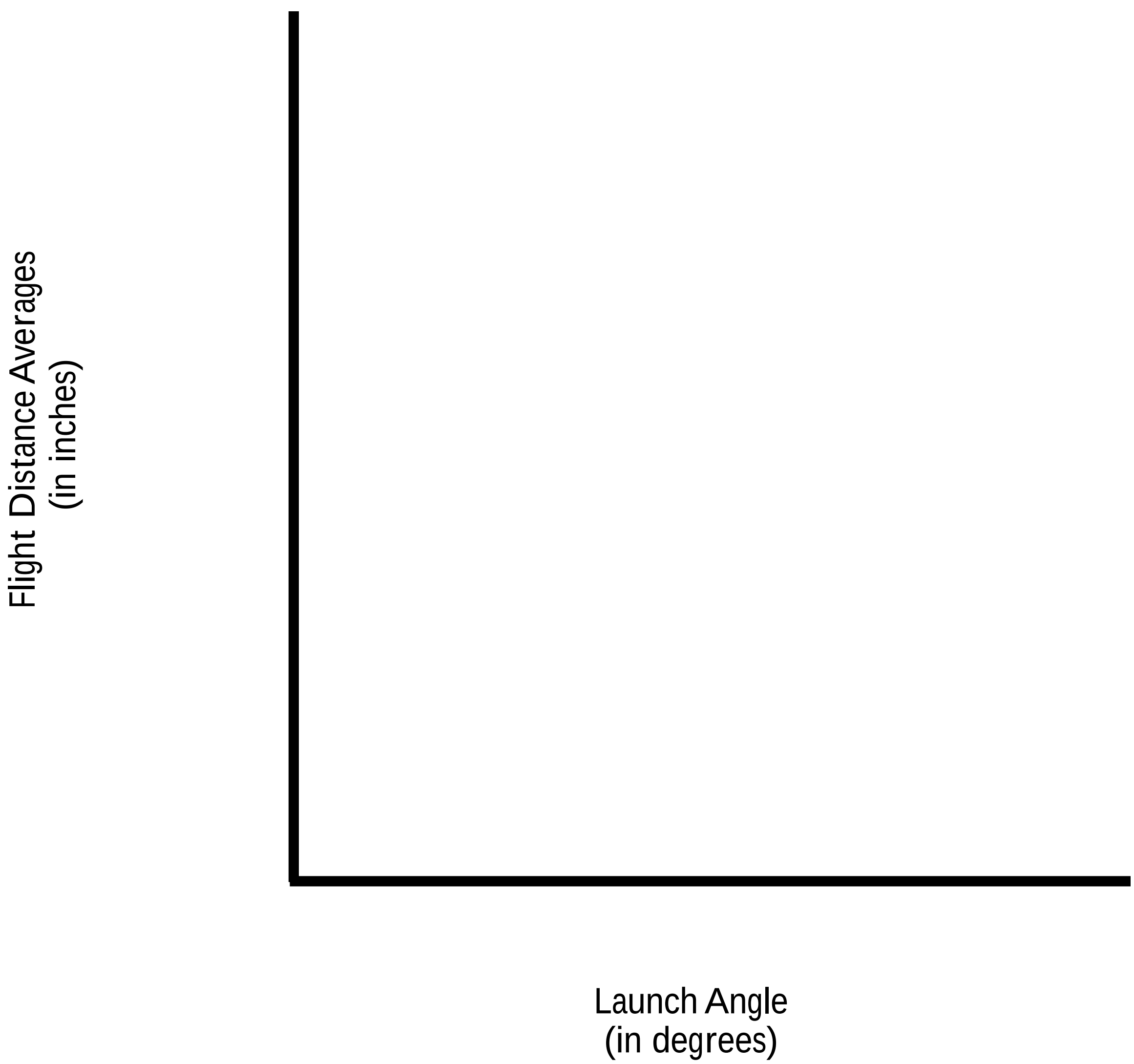
Launch Angle (in degrees)	Flight distance in inches			Median	Average
	Flight 1	Flight 2	Flight 3		

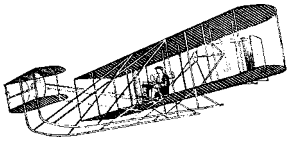
Conclusion: Explain what your experiment's results mean.

Launch Angle
Average Flight Distance
For

____

Name of Airplane





Experiment Procedure Card and Data Sheet
Teacher Key

What question do I want to answer?

Answers will vary, so here are some examples.

- *What is the best launch angle for takeoff for this airplane?*

- *Which angle of attack will give the greatest lift during takeoff?*

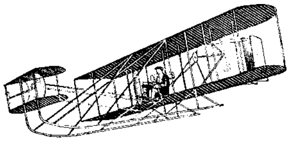
What do I think will happen during this experiment?

Answers will vary, so here are some examples.

- *I think the smallest (greatest) angle will give the greatest lift because of the way it makes the air flow over the wing. Faster air will flow over the top of the wing than underneath because the wings are tilted into the wind more.*

- *I think the greatest (least) angle will give the greatest lift because more air will be moving over the top than underneath (or vice versa).*

- *I think the best airflow will happen at an angle in between because too great of an angle will not allow as much air to flow over the top of the wing and the flow will break up and become turbulent. It will cause the air to flow faster over the top of the wing than underneath the wing. This will cause a difference in air pressure between the top and bottom and create the best lift.*



Experiment Procedure Card and Data Sheet
Teacher Sample Key

Launch Angle (in degrees)	Flight distance in inches			Median	Average
	Flight 1	Flight 2	Flight 3		
10 degrees	177	204	200	200	193
20 degrees	182	206	209	206	199
30 degrees	91	88	87	88	88
40 degrees	55	70	67	67	64

Conclusion: Explain what your experiment's results mean.

According to our results, the launch angle that gives the greatest amount of lift is about 20 degrees. The distance gained was only a little bit farther than the 10-degree angle (6 inches). This leads us to suspect that if we would experiment further and try a launch at a 15-degree angle and another at a 25-degree angle, we could pinpoint even more precisely what the best angle of attack is for takeoff for this airplane model.

Launch Angle
Average Flight Distance
For

Teacher Sample Key
Name of Airplane